Acute Stress and Event-Related Potential Correlates of Attention to Alcohol Images in Social Drinkers

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ABSTRACT. Objective: The use of alcohol to cope with stress is a major health concern, yet the neurophysiological mechanisms underlying the effects of stress on alcohol-related cognition are not well understood. This study examined changes in event-related potentials (ERPs) elicited by alcohol-related images before and after a stressor compared with a control condition. **Method:** Social drinkers ($N = 75$; 38 male) were assigned to one of two target subgroups for completion of an oddball task: (a) to detect alcohol targets while ignoring household object distracters and frequently presented nonsense shapes or (b) to detect object targets while ignoring alcohol distracters and nonsense shapes. ERPs were recorded before and after one of two conditions: a stressor or a nonstressful control task. **Results:** N200 latency and amplitude changes were

modulated by stress. Similarly, stress reduced P300 latencies beyond practice effects. For P300 amplitude, the target subgroup interacted with the condition such that the standard “oddball” effect was observed in the control condition but was absent in the stress condition, suggesting that stress may have interfered with the participants’ cognitive efficiency, or the ability to ignore task-irrelevant stimuli. **Conclusions:** These findings suggest that stress influences the early stages of alcohol-related processing, an effect that may be particularly apparent in ERP latencies. These findings have implications for understanding the neural mechanisms involved with stress and alcohol cue reactivity. (*J. Stud. Alcohol Drugs*, 73, 761–771, 2012)

CONSUMPTION OF ALCOHOL as a coping mechanism to deal with stress is a major health concern in our society. Among alcohol-dependent individuals, stress and anxiety may enhance the urge to consume alcohol (Volkow and Li, 2004), promote relapse, and negatively influence treatment prognosis (Fox et al., 2007; Silberman et al., 2009). Social drinkers may also view drinking as a means of reducing stress (see Veenstra et al., 2006, for review), despite drinking to cope frequently increasing negative life events and thus stress levels, thereby creating a vicious circle (Pohorecky, 1991). Stress and anxiety have been linked to alcohol consumption in rodent models; however, additional work is needed to elucidate the neurophysiological mechanisms underlying these interactions in humans. This has been identified as an important focus of future research in clinical neuroscience (Sinha and Li, 2007).

One model for examining stress and alcohol consumption in humans involves the evaluation of physiological responsiveness to alcohol cues and/or behavioral measures of attentional bias to alcohol-related stimuli. A number of studies have examined cue reactivity and attentional bias

to alcohol-related images under conditions of intoxication, withdrawal, or stress. The Baker et al. (2004) model posits that negative affect might cause substance-related cues to grab attention automatically before the cues cross the threshold of conscious awareness (Field and Powell, 2007). Using a visual probe task measuring controlled features of visual-spatial processing in relation to alcohol-related stimuli, Field and colleagues (2004) demonstrated that attentional bias may be amenable to conscious control when stimuli are presented for periods in excess of 500 ms. This effect is enhanced by stress and is most pronounced when an individual’s motivation to obtain the depicted substance is at its greatest level (Field and Powell, 2007).

Neuroimaging studies have examined anatomical correlates of such effects in humans. Results suggest that corticostriatal limbic circuitry underlies both affective and reward processing (Sinha and Li, 2007). Stress- and drug-induced craving involves brain regions (e.g., medial prefrontal, anterior and posterior cingulate, and striatal and posterior insular areas), which are also involved in anxiety, emotion, and behavioral self-control (Beauregard et al., 2001; Peoples, 2002; Phan et al., 2002; Sinha and Li, 2007). It is therefore not surprising that imaging studies of cue reactivity in substance-dependent populations have implicated a number of these structures (i.e., cingulate gyrus, medial prefrontal and orbitofrontal cortices, and insular and dorsolateral prefrontal cortices) (Sinha and Li, 2007). Deeper structures have also been implicated (i.e., ventral tegmental area, hippocampus, and amygdala). However, less is known about

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cue-related activation among nondependent social drinkers and those who are at risk for substance use disorders based on family history or other factors.

Appetitive behaviors such as alcohol consumption can be conceptualized to occur under the influence of two kinds of processes: automatic processing (e.g., early, pre-perceptual, and approach oriented) and controlled processing (e.g., late, attention dependent, and self-regulatory) (Wiers et al., 2007). It is posited that, in dependence, early appetitive responses are reinforced, whereas later self-regulatory processes are weakened (Wiers et al., 2007). Given the expectancy that alcohol helps to relieve stress (see Veenstra et al., 2006, for review), individuals with these beliefs might be expected to exhibit attentional biases to alcohol-related stimuli when stressed (e.g., Field and Powell, 2007). Timing is an important consideration in the measurement of automatic versus controlled processing. To date, these processes have not been adequately examined using "online" attentional measures, such as event-related potentials (ERPs), in which cortical responses may be ascertained within milliseconds of cue presentation (Sher et al., 2007). Although neuroimaging techniques such as functional magnetic resonance imaging offer superior spatial resolution, they are limited in terms of temporal sensitivity. With their superior temporal resolution, ERPs are an ideal method for examining this issue.

A number of studies have found that the P300 ERP—occurring approximately 300 ms following infrequent, task-relevant stimuli—is sensitive to the arousal value of emotional stimuli, having larger amplitudes for more highly arousing stimuli (Delplanque et al., 2006). This variant of the P300 is attention dependent and is an index of controlled processing (Realmuto et al., 1993). The P300 is often preceded by a central negativity (N200), which is also sensitive to emotion and substance-related attentional biases (Carretié et al., 2004), and is thought to reflect automatic processing (Realmuto et al., 1993). Previous findings suggest that emotional stimuli activate motivational, appetitive systems to enhance automatic processing, resulting in larger amplitudes and/or shorter latencies of ERPs (Carretié et al., 2004; Schupp et al., 2006). This prioritized processing can then either interfere with or enhance subsequent controlled processes of stimulus evaluation and/or decision-making (Compton, 2003). Given that images of alcohol are known to stimulate appetitive processes (Field and Powell, 2007) and that stress can enhance motivation to drink alcohol (Volkow and Li, 2004), it is logical to predict that alcohol-related images might elicit interactions of emotion and attention among social drinkers.

In the current study, N200 and P300 waveforms were elicited by a visual three-stimulus oddball paradigm. Participants were assigned to one of two target subgroups: (a) to detect alcohol targets while ignoring household object distracters and frequently presented nonsense shapes or (b)

to detect object targets while ignoring alcohol distracters and nonsense shapes. ERPs were recorded before and after one of two manipulations: a stressor (Paced Auditory Serial Addition Test [PASAT]) or a nonstressful control task (Bejeweled2). This design allowed examination of between-subjects effects of experimental condition (stress vs. control) and target subgroup (alcohol image targets vs. household image targets), along with within-subjects effects of time (pre- vs. post-manipulation) and stimulus type (alcohol images vs. household images) and interactions of these factors. To our knowledge, this study is among the first to examine the sensitivity of N200 and P300 ERPs to stress. Stress was expected to increase amplitude and/or decrease latency of ERPs to alcohol images compared with the control condition (e.g., an interaction of Time $\times$ Experimental Condition was hypothesized). For stimulus effects, it was hypothesized that, if attentional capture by alcohol images is mediated by automatic processes, then ERPs to alcohol images would show enhancement independent of task relevance (e.g., main effect of stimulus-type effects across target subgroups). However, if attentional capture is mediated by controlled processes, ERPs to alcohol images would vary as a function of target subgroup (e.g., an interaction of Stimulus Type $\times$ Target Subgroup).

Method

Participants

Seventy-five social drinkers ($n_{\text{men}} = 38$) participated; all reported at least light social drinking (Chen et al., 2006). All had normal or corrected vision. Participants were reimbursed at the rate of \$15 per hour.

Institutional Review Boards at Texas State University–San Marcos and the University of Texas at San Antonio approved all materials, and informed consent was obtained. Participants were recruited primarily from the university setting using flyers and word-of-mouth. Initially, participants were screened by telephone regarding their physical and psychological health, medications, and personal alcohol consumption and drug use history. Individuals reporting current medications influencing the stress response and those with a personal history of neuropathology, seizures, head injury, loss of consciousness for more than 20 minutes, or Axis I psychiatric diagnoses were excluded.

Laboratory protocol

An outline of the testing session is shown in Table 1. Participants were assigned either to a stress condition in which ERPs were collected before and after administration of the PASAT or to a nonstress control condition in which ERP sessions were conducted before and after participants played Bejeweled2. During the ERP task, participants responded to

either alcohol targets or object targets (e.g., household items, including nonalcoholic beverages), depending on their target subgroup assignment. Thus, four categories were created by the crossing of experimental condition and target subgroup: stress/alcohol targets ($n = 20$), stress/objects ($n = 19$), control/alcohol targets ($n = 18$), and control/objects ($n = 18$).

Background variables. Before ERP data collection, participants completed basic demographic questionnaires as well as the Beck Depression Inventory (Beck et al., 1996), the Spielberger State–Trait Anxiety Inventory (SSAI; Spielberger, 1983), and a quantity–frequency index (QFI; Cahalan et al., 1969) of alcohol use. Participants maintained their regular intake of tobacco and caffeine (if applicable). This strategy minimized both cognitive facilitation and acute withdrawal effects. Distribution of smokers and caffeine users did not differ by condition, target subgroup, or gender ($ps > .11$).

Electrophysiology. ERP data were collected in a sound-insulated, radiofrequency-shielded recording chamber. Behavioral measures were recorded using a push-button response pad. Continuous electroencephalogram (EEG) was recorded from a geodesic array of 64 active Ag–AgCl electrodes (BioSemi ActiveTwo, BioSemi B.V., Amsterdam, The Netherlands; see Wicha et al., 2004) held in place by an electrode cap. Eye movements were monitored with electrodes below the left and right eyes and at the outer canthi. Electrodes were placed on both mastoids for offline re-referencing. Electrode offsets were maintained within a range of ± 30 mV. The EEG signal was sampled at a rate of 512 Hz and amplified with a bandpass of 0.16 to 100 Hz by a BioSemi ActiveTwo amplifier. Data were referenced offline to the average of both mastoids. Trials containing eye blinks, eye movement, and excessive artifacts (absolute amplitude > 100 μ V) were removed offline. After artifact rejection, 1,000-ms stimulus-locked averages with a 100-ms pre-stimulus baseline were used to extract the ERPs, which were digitally bandpass-filtered from 0.1 to 35 Hz. To ensure adequate signal-to-noise ratios, data from participants contained at least 20 artifact-free trials per item category.

Three-stimulus oddball paradigm. Individual color images from the public domain were retrieved via Internet

searches (e.g., mug of beer = alcohol-related image; tea pot = household object; stimuli are available from the first author), edited to present a single item on a white background and matched for contrast and luminance. Presentation parameters were based on oddball tasks by Rodríguez Holguín and colleagues (1999) and modified for picture presentation (Herrmann et al., 2001). Forty-eight target (probability = .10), 48 novel nontarget (probability = .10), and 384 frequent neutral distracter stimuli (color nonsense shapes; DeSchepper and Treisman, 1996; probability = .80) were presented at the center of a computer monitor for 500 ms (Mogg et al., 2004), replacing a central fixation cross that was presented for 500 ms. The stimuli were 8 cm wide $\times$ 12 cm high. The inter-stimulus interval varied randomly (750, 1,000, and 1,250 ms). Two variations of the task were presented (e.g., alcohol or object targets), and participants were instructed to respond to their assigned target using their dominant hand. Presentation occurred in two blocks: one block before the manipulation and one block after the manipulation (e.g., pre- and post-PASAT for participants assigned to the stressor condition and pre- and post-Bejeweled for participants assigned to the control condition). Each block consisted of three runs (224 trials) interspersed with rest periods.

Stress and anxiety measures

Acute stress task. For the PASAT (Gronwall, 1977), participants attended to the auditory presentation of single-digit numbers and responded by verbally indicating the sum of the number just heard and the number heard immediately prior. This task elicits negative mood states and autonomic arousal (Mathias et al., 2004). Numbers (1–9) were presented in a randomized format in four trials. Each trial consisted of 60 numbers presented with progressively faster rates of stimulus presentation (2.4-, 2.0-, 1.6-, and 1.2-second inter-stimulus intervals), increasing the intensity of stimulation over time. The aversive nature of the task was verified by state anxiety levels.

Control task. For Bejeweled2 (www.popcap.com/games/bejeweled2), participants were rewarded with points based on their ability to create links of three “jewels” in a row, using characteristics such as the shape and color of the objects. There was no time constraint. The game continued for 15 minutes, approximately equivalent to the PASAT duration. Performance characteristics were recorded, but participants were given no feedback regarding quality. The nonaversive nature of this task was verified by state anxiety levels.

State anxiety. The SSAI consists of 20 statements that evaluate how participants are feeling “right now, at this moment.” It was repeated five times to measure anxiety in response to the PASAT or Bejeweled2. State anxiety is known to increase in response to psychological stress (Boye and Malt, 2002).

TABLE 1. General outline of the laboratory testing session

Time	Task(s)	Duration, in minutes
1:30 P.M.	Consent, survey, SSAI	40–50
2:20 P.M.	EEG preparation	20–30
2:50 P.M.	SSAI, ERP ₁	15–20
3:10 P.M.	SSAI, manipulation ^a	15–20
3:30 P.M.	SSAI, ERP ₂	15–20
3:50 P.M.	SSAI, electrode removal	10
4:00 P.M.	Debriefing, exit laboratory	

Notes: SSAI = Spielberger State–Trait Anxiety Inventory; EEG = electroencephalogram; ERP₁ = event-related potential task block 1; ERP₂ = event-related potential task block 2. ^aPaced Auditory Serial Addition Test or Bejeweled2.

Data analysis

Background variables. Chi-square analyses examined the distribution of gender and ethnicity. Age, years of education, trait anxiety, depression, QFI, age at first drink, age at first drunken episode, age at first regular pattern of drinking, and days since last alcohol use were examined via separate analyses of variance (ANOVAs) based on experimental condition (stress vs. control), target subgroup (alcohol vs. object target), gender (male vs. female), and their interaction. Interactions were interpreted using simple effects tests, and type 1 error was minimized by using an α level of .01.

Manipulation check. Stress induction was verified via 5 (assessment) $\times$ 2 (condition) $\times$ 2 (target subgroup) $\times$ 2 (gender) repeated-measures ANOVA. Degrees of freedom were adjusted for violations of sphericity using Greenhouse-Geisser corrections. Post hoc analyses for assessment effects consisted of pair-wise comparisons of each assessment (α level = .01). Post hoc analyses for between-subjects interactions consisted of simple effects tests examining group differences within each condition (α level = .01).

Behavioral and electrophysiological analyses. Accuracy and reaction time to detect targets were analyzed via repeated-measures ANOVAs with time (pre- vs. post-manipulation) as the within-subjects factor and condition, target subgroup, and gender as between-subjects factors. Interactions were interpreted using planned comparisons with an α level of .01 to minimize type 1 error; specific comparisons are detailed within the Results section. For

four-way interactions involving time, difference scores were used for simplification (i.e., post-manipulation reaction time minus pre-manipulation).

ERP analyses focused on amplitudes and latencies of the N200 and P300 for infrequent target and nontarget stimuli. The P300 was defined as a positive peak 350–600 ms post-stimulus at centroparietal sites. The N200 was identified as a negative-going peak 250–400 ms post-stimulus at fronto-central sites; however, it was also evident over centroparietal sites before the P300.

Peak latencies of each component of each type were verified by two independent coders, with discrepancies resolved through mutual agreement. Based on peak latencies, mean amplitudes (± 20 ms around each peak) were determined. For simplification, N200 amplitude and latency changes were indexed by the average activity of left medial frontal (LMFr), right medial frontal (RMFr), and midline frontal (MiFr) electrodes. P300 amplitude was derived from the average activity of left medial parietal (LMPa), right medial parietal (RMPa), and midline parietal (MiPa) electrodes.

To clarify whether amplitude/latency differences for the P300 were driven by characteristics of the foregoing N200, N2/P3 amplitude and latency differences (e.g., P300 minus N200 amplitude and latency; Realmuto et al., 1993) were analyzed using values derived from the average activity of LMPa, RMPa, and MiPa.

Amplitude and latency of N200, P300, and N2/P3 differences were analyzed via repeated-measures ANOVA using within-subject factors of time and stimulus type and

TABLE 2. Background characteristics of participants: Means (with standard deviations in parentheses)^a

Variable	Stress condition group				Control condition group			
	Alcohol target subgroup (SA)		Object target subgroup (SO)		Alcohol target subgroup (CA)		Object target subgroup (CO)	
	Males (n = 12)	Females (n = 8)	Males (n = 8)	Females (n = 11)	Males (n = 9)	Females (n = 9)	Males (n = 9)	Females (n = 9)
Age	24.7 (3.1)	23.4 (3.4)	23.4 (3.7)	24.0 (2.0)	23.4 (3.7)	24.3 (3.7)	22.0 (0.9)	23.1 (3.6)
Years of education ^a	16.0 (2.5)	15.4 (1.8)	14.8 (2.2)	16.1 (0.7)	14.9 (1.1)	16.2 (1.9)	15.4 (1.2)	14.6 (1.4)
Trait anxiety ^b	31.58 (8.53)	41.62 (10.81)	39.62 (6.00)	37.82 (12.26)	35.67 (10.32)	37.89 (10.27)	30.78 (6.40)	35.44 (11.35)
Depression ^{a,c}	5.25 (5.01)	12.75 (8.48)	13.00 (5.29)	6.36 (8.03)	7.56 (6.02)	11.22 (6.38)	3.22 (2.77)	9.00 (12.38)
QFI ^d	1.29 (1.23)	1.34 (1.68)	1.38 (1.05)	0.78 (0.62)	2.30 (4.04)	1.14 (1.62)	0.79 (0.39)	0.85 (0.70)
Age at first drink ^e	12.4 (3.9)	11.0 (6.5)	14.4 (3.5)	11.6 (6.4)	12.0 (3.6)	12.1 (4.6)	12.2 (3.3)	13.7 (3.5)
Age at first drunken episode	16.5 (2.6)	17.1 (4.0)	17.8 (2.3)	16.8 (2.7)	15.9 (1.8)	17.6 (2.2)	17.1 (1.9)	15.9 (1.6)
Age at first regular drinking pattern ^e	18.5 (2.4)	19.4 (2.5)	19.8 (1.7)	19.8 (3.2)	18.4 (1.9)	19.9 (1.3)	18.6 (1.9)	18.4 (0.9)
Days since last alcohol use	5.5 (8.5)	2.6 (1.2)	2.1 (1.2)	2.6 (2.0)	3.8 (2.6)	2.4 (1.3)	3.7 (2.3)	4.0 (4.1)

Notes: QFI = quantity–frequency index. ^aExperimental Condition $\times$ Target Subgroup $\times$ Gender interaction—years of education: $F(1, 67) = 6.64, p = .01$; depression: $F(1, 67) = 5.78, p = .02$; alpha-adjusted follow-up analyses were nonsignificant; ^bSpielberger State–Trait Anxiety Questionnaire (Spielberger, 1983); baseline anxiety was not clinically significant; ^cBeck Depression Inventory, Version 2 (Beck et al., 1996); depression was not clinically significant; ^dquantity–frequency index (Cahalan et al., 1969) = ounces of absolute ethanol per day during the previous 6-month period; ^emissing data: males-SA: $n = 11$ for age at first drink; females-SA: $n = 7$ for first regular drinking pattern. Males-CO: $n = 8$ for age at first regular drinking pattern.

between-subject factors of condition, target subgroup, and gender. For both amplitude and latency analyses, interactions were interpreted using planned comparisons with an α level of .01 to minimize type 1 error; specific comparisons are detailed within the Results section. For four-way interactions involving time, difference scores were used for simplification (i.e., post-manipulation amplitude minus pre-manipulation).

Results

Background variables

Gender was equally distributed across the four experimental groups ($p = .74$), and ethnicity (Hispanic vs. non-Hispanic) was equally distributed across gender and group ($ps > .34$). As shown in Table 2, differences were nonsignificant for age, trait anxiety, QFI, age at first drink, age at first drunken episode, age at first regular drinking pattern, and days since last drink ($ps > .05$). Interactions of Condition $\times$ Target Subgroup $\times$ Gender were noted for years of education, $F(1, 67) = 6.64, p = .01$, and depression, $F(1, 67) = 5.78, p = .02$; however, subsequent comparisons failed to reach statistical significance following alpha adjustment.

Manipulation check

Anxiety levels differed across Assessments 1–5, $F(2.90, 194.51) = 12.87, p < .001$, and the expected interaction of Assessment $\times$ Condition was observed, $F(2.92, 194.51) = 14.40, p < .001$. Higher anxiety occurred immediately after the stressor (Assessment 4) relative to all other assessments ($ps < .001$); thus, the PASAT was aversive. Bejeweled2 was nonaversive, as Assessments 1–4 did not differ. Further, Assessment 5 was lower than Assessments 1–3 ($ps \leq .001$) and did not differ from Assessment 4. Condition, target subgroup, and gender interacted, $F(1, 67) = 4.85, p = .03$; however, simple effects tests were nonsignificant following alpha adjustment. No other significant effects were noted.

Behavioral results

Target detection accuracy was approximately 96% and did not differ by time, condition, or gender ($ps > .35$). Time and gender interacted, $F(1, 70) = 5.0, p = .03$; however, subsequent analyses were nonsignificant following alpha correction.

Reaction time decreased following the manipulation (535.96 ms, $SE = 8.38$, vs. 516.11 ms, $SE = 6.15$), $F(1, 67) = 20.92, p < .001$. Effects of condition, stimulus type, gender, and their interactions were nonsignificant ($ps > .07$). A target subgroup main effect was noted, $F(1, 67) = 8.51, p = .005$. Reaction times of the alcohol target subgroup were shorter compared with the object target subgroup (505.39 ms, $SE = 9.90$, vs. 546.41 ms, $SE = 9.99$).

Event-related potentials

Figure 1 shows the grand-averaged ERPs at the midline centroparietal site for the two stimulus types and response conditions before and after PASAT or Bejeweled2. Significant effects, estimated marginal means, and standard error for amplitude and latency are summarized in Tables 3 and 4, respectively.

N200 amplitude. Main effects of time were significant, $F(1, 67) = 23.23, p < .001$ (greater negativity post-manipulation). Stimulus type was also significant, $F(1, 67) = 7.33, p = .009$ (greater negativity to objects); further, stimulus type and target subgroup interacted, $F(1, 67) = 11.33, p = .001$. In the alcohol target subgroup, objects (vs. alcohol) elicited greater negativity, $t(1, 37) = 4.15, p < .001$, a pattern absent in the object target subgroup ($p = .50$). Three-way (Time $\times$ Stimulus Type $\times$ Target Subgroup), $F(1, 67) = 6.14, p = .02$, and four-way (Time $\times$ Stimulus Type $\times$ Experiment $\times$ Target Subgroup), $F(1, 67) = 9.45, p = .003$, interactions were also observed. Between-subjects effects of condition, target status, gender, and their interactions were nonsignificant; no other significant effects were noted ($ps \geq .09$).

THREE-WAY INTERACTION: Analyses within the alcohol target subgroup confirmed the effects of time, $F(1, 37) = 15.22, p < .001$ (greater negativity post-manipulation), and stimulus type, $F(1, 37) = 17.23, p < .001$ (greater negativity to objects). A Time $\times$ Stimulus Type interaction failed to reach statistical significance following alpha adjustment. Within the object target subgroup, time was significant, $F(1, 36) = 9.85, p = .003$ (greater negativity post-manipulation); no other effects were noted.

FOUR-WAY INTERACTION: Analyses of amplitude difference scores within the stress condition revealed no significant effects of stimulus type, target subgroup, or their interaction ($ps > .17$). For the nonstress control condition, there was an interaction of Stimulus Type $\times$ Target Subgroup, $F(1, 34) = 12.71, p = .001$. The alcohol target subgroup exhibited greater manipulation-related negativity to objects vs. alcohol, $t(17) = 2.80, p = .01$. In the object target subgroup, differences were nonsignificant following alpha adjustment.

P300 amplitude. No significant effects of time were noted ($ps > .08$). There was a main effect of stimulus type, $F(1, 67) = 25.66, p < .001$ (greater positivity to alcohol images), and an interaction of Stimulus Type $\times$ Target Subgroup, $F(1, 67) = 44.85, p < .001$, in which alcohol images elicited greater positivity within the alcohol target subgroup, $t(37) = 7.99, p < .001$, with no significant differences in the object target subgroup ($p = .19$). There was also a three-way interaction of Time $\times$ Stimulus Type $\times$ Target Subgroup, $F(1, 67) = 15.97, p < .001$, and a four-way interaction of Time $\times$ Stimulus Type $\times$ Experimental Condition $\times$ Target Subgroup, $F(1, 67) = 6.92, p = .01$. Between-subjects effects of condition, target status, gender and their interactions were nonsignificant; no other significant effects were noted ($ps \geq .06$).

FIGURE 1. Grand averages of N200 and P300 event-related potentials to alcohol and object images as a function of target status (i.e., presented as targets vs. nontargets) for A) the stressor condition (Paced Auditory Serial Addition Test [PASAT] administration) and B) the control task condition (Bejeweled2 administration). Overall, N200 latency and amplitude changes were modulated by stress, and stress reduced P300 latencies beyond mere practice effects. The standard “oddball” effect on P300 amplitude was observed in the control condition but not in the stress condition, suggesting that stress may have interfered with the participants’ ability to ignore task-irrelevant stimuli.

TABLE 3. Significant effects on amplitude (microvolts)

	Significant effects	Significant planned comparisons and means (with standard errors in parentheses)
N200	Time, $p < .001$	Pre-manipulation: -4.01 (0.58); post: -5.49 (0.63)
	Stimulus type, $p = .009$	Object images: -5.16 (0.56); alcohol: -4.34 (0.64)
	Stimulus Type $\times$ Target Subgroup, $p = .001$	<i>Alcohol target subgroup</i> : stimulus type, $p < .001$ • Object images: -6.10 (0.87); alcohol: -4.33 (0.99)
	Time $\times$ Stimulus Type $\times$ Target Subgroup, $p = .02$	<i>Alcohol target subgroup</i> : time, $p < .001$; stimulus type, $p < .001$ • Pre-manipulation: -4.36 (0.92); post: -6.07 (0.94) • Object images: -6.10 (0.87); alcohol: -4.33 (0.99)
	Time $\times$ Stimulus Type $\times$ Target Subgroup $\times$ Condition, $p = .003$	<i>Object target subgroup</i> : time, $p < .003$ • Pre-manipulation: -3.61 (0.75); post: -4.90 (0.81) <i>Control condition</i> : Stimulus Type $\times$ Target Subgroup, $p = .001$ <i>Alcohol target subgroup</i> : stimulus type, $p = .01$ • Object images: -3.74 (1.03); alcohol: -0.41 (0.85) ^a
P300	Stimulus type, $p < .001$	Object images: 9.54 (0.70); alcohol: 12.04 (0.72)
	Stimulus Type $\times$ Target Subgroup, $p < .001$	<i>Alcohol target subgroup</i> : $p < .001$ • Object images: 9.07 (1.06); alcohol: 14.80 (1.09)
	Time $\times$ Stimulus Type $\times$ Target Subgroup, $p < .001$	<i>Alcohol target subgroup</i> : stimulus type, $p < .001$ • Object images: 9.07 (1.06); alcohol: 14.80 (1.09)
	Time $\times$ Stimulus Type $\times$ Target Subgroup $\times$ Condition, $p = .01$	<i>Object target subgroup</i> : Time $\times$ Stimulus Type, $p = .003$ • Post-manipulation: stimulus type, $p = .01$ • Object images: 10.78 (0.88); alcohol: 8.85 (0.89) <i>Control condition</i> : Stimulus Type $\times$ Target Subgroup, $p < .001$ <i>Alcohol target subgroup</i> : stimulus type, $p = .01$ • Object images: -0.75 (0.86); alcohol: 2.99 (0.82) ^a
N2/P3 ^b	Time, $p = .001$	<i>Object target subgroup</i> : stimulus type, $p = .003$ • Object images: 2.75 (0.69); alcohol: -0.68 (0.77) ^a
	Stimulus type, $p = .03$	Pre-manipulation: 10.73 (0.54); post: 12.07 (0.50)
	Target subgroup, $p = .01$	Object images: 10.86 (0.53); alcohol: 11.94 (0.55)
	Stimulus Type $\times$ Target Subgroup, $p < .001$	<i>Alcohol target subgroup</i> : 12.62 (0.68); object target: 10.17 (0.69) <i>Alcohol target subgroup</i> : $p < .001$ • Object images: 10.84 (0.70); alcohol: 14.35 (0.72)
	Time $\times$ Stimulus Type $\times$ Target Subgroup, $p = .007$	<i>Alcohol target subgroup</i> : time, $p = .001$; stimulus type, $p < .001$ • Pre-manipulation: 14.35 (0.72); post: 10.84 (0.70) • Object images: 13.49 (0.72); alcohol: 11.69 (0.64) <i>Object target subgroup</i> : Time $\times$ Stimulus Type, $p = .001$ • Object images: time, $p = .003$ • Pre-manipulation: 9.86 (0.85); post: 11.82 (0.79)

^aFour-way interactions with time were interpreted using a simplification (post-manipulation amplitude minus pre-manipulation); ^bN2/P3 latency = P300 latency minus N200 latency.

THREE-WAY INTERACTION: In the alcohol target subgroup, stimulus type was the only factor that retained statistical significance following alpha adjustment, $F(1, 37) = 63.79$, $p < .001$ (greater positivity to alcohol images). In the object target subgroup, a Time $\times$ Stimulus Type interaction was noted, $F(1, 36) = 9.99$, $p = .003$, in which amplitude to objects was significantly larger (vs. alcohol) post-manipulation, $t(36) = 2.68$, $p = .01$, and pre-manipulation differences were nonsignificant ($p = .72$).

FOUR-WAY INTERACTION: Analysis of amplitude difference scores within the stress condition revealed only nonsignificant effects ($ps > .33$). In the nonstress control condition, a Stimulus $\times$ Target Status interaction was noted, $F(1, 34) = 18.62$, $p < .001$, in which the alcohol target subgroup exhibited a larger amplitude increase in response to alcohol images, $t(17) = 2.81$, $p = .01$. The object target subgroup exhibited the opposite pattern, $t(17) = -3.44$, $p = .003$ (greater positivity to objects). In other words, participants assigned to the control task condition showed amplitude increases over

time in response to assigned targets, whereas participants assigned to the stressor did not show this pattern.

N2/P3 amplitude differences. Main effects of time, $F(1, 67) = 12.69$, $p = .001$ (post-manipulation > pre-manipulation), stimulus type, $F(1, 67) = 5.01$, $p = .03$ (alcohol > objects), and target subgroup, $F(1, 67) = 6.38$, $p = .01$ (alcohol targets > object targets), were significant. An interaction of Stimulus Type $\times$ Target Subgroup was also noted, $F(1, 67) = 24.70$, $p < .001$, in which the alcohol target subgroup exhibited larger N2/P3 deflections to alcohol images, $t(37) = 5.50$, $p < .001$; no differences were noted within the object target subgroup ($p = .07$). A three-way interaction of Time $\times$ Stimulus Type $\times$ Target Subgroup, $F(1, 67) = 7.73$, $p = .007$, was also noted. Between-subjects effects of condition, gender, and their interactions were nonsignificant; no other effects were observed ($ps \geq .28$).

THREE-WAY INTERACTION: Within the alcohol target subgroup, N2/P3 deflections were enhanced after both manipulations, $F(1, 37) = 13.57$, $p = .001$, and were larger overall for alco-

TABLE 4. Significant effects on latency (milliseconds)

Significant effects		Significant planned comparisons and means (with standard errors in parentheses)
N200	Time, $p < .001$	Pre-manipulation: 333.23 (3.22); post: 307.96 (3.25)
	Time $\times$ Condition, $p = .001$	<i>Stress condition</i> : time, $p < .001$ • Pre-manipulation: 333.11 (4.17); post: 297.79 (4.23)
		<i>Control condition</i> : time, $p = .002$ • Pre-manipulation: 333.87 (4.61); post: 318.09 (4.80)
	Stimulus Type $\times$ Condition, $p = .001$	<i>Control condition</i> : stimulus type, $p = .007$ • Object images: 330.53 (4.62); alcohol: 321.43 (4.05)
	Stimulus Type $\times$ Condition $\times$ Gender, $p = .03$	<i>Females in control condition</i> : stimulus type, $p = .004$ • Object images: 332.32 (6.44); alcohol: 317.74 (4.39)
P300	Stimulus Type $\times$ Condition $\times$ Target Status $\times$ Gender, $p = .04$	<i>Females in control condition</i> : stimulus type, $p = .005$ • Object images: 332.32 (6.60); alcohol: 317.14 (4.52)
	Time $\times$ Stimulus Type $\times$ Target Subgroup $\times$ Condition, $p = .007$	n.s. following alpha adjustment
	Time, $p < .001$	Pre-manipulation: 457.04 (5.77); post: 437.27 (5.79)
	Condition, $p = .004$	Stressor: 430.97 (7.53); control: 463.33 (7.71)
	Stimulus type, $p = .002$	Object images: 454.03 (5.91); alcohol: 440.27 (5.67)
N2/P3 ^a	Time $\times$ Stimulus Type, $p = .03$	<i>Post-manipulation</i> : stimulus type, $p = .001$ • Object images: 446.27 (7.22); alcohol: 425.84 (6.46)
	Time $\times$ Condition, $p = .03$	<i>Stress condition</i> : time, $p < .001$ • Pre-manipulation: 443.89 (8.14); post: 415.67 (7.61)
	Stimulus type, $p = .02$	Object images: 132.07 (5.12); alcohol: 121.05 (5.48)
	Condition, $p = .02$	Stressor: 115.76 (6.69); control: 137.35 (6.85)

Notes: n.s. = not significant. ^aN2/P3 latency = P300 latency minus N200 latency.

hol targets, $F(1, 37) = 30.24$, $p < .001$. Time and stimulus type did not interact ($p = .28$). In the object target subgroup, time and stimulus type did interact, $F(1, 36) = 11.97$, $p = .001$, in that time was a significant factor for object images, $t(36) = 3.19$, $p = .003$ (greater deflection post-manipulation) but not for alcohol images ($p = .83$).

N200 latency. Time was a significant factor, $F(1, 67) = 83.69$, $p < .001$ (shorter latency post-manipulation), and time interacted with condition, $F(1, 67) = 11.79$, $p = .001$, such that latency decreased following the stressor, $t(38) = 12.14$, $p < .001$. A similar, but smaller, latency reduction was noted in the control condition, $t(35) = 3.28$, $p = .002$. Stimulus type also interacted with condition, $F(1, 67) = 11.38$, $p = .001$, such that latency did not differ between image types in the stress condition, but alcohol images elicited a shorter latency (vs. object images) in the nonstress condition, $t(35) = 2.85$, $p = .007$. A three-way interaction of Stimulus Type $\times$ Condition $\times$ Gender, $F(1, 67) = 4.97$, $p = .03$, was noted, along with two types of four-way interactions: Stimulus Type $\times$ Condition $\times$ Target Status $\times$ Gender, $F(1, 67) = 4.56$, $p = .04$, and Time $\times$ Stimulus Type $\times$ Target Subgroups $\times$ Condition, $F(1, 67) = 7.83$, $p = .007$.

THREE-WAY INTERACTION: Separate comparisons were conducted for each condition/gender combination. Females in the control condition exhibited shorter latency to alcohol images (vs. objects), $t(17) = 3.33$, $p = .004$. Other effects were nonsignificant ($ps > .08$).

FOUR-WAY INTERACTIONS: Stimulus Type $\times$ Condition $\times$ Target Status $\times$ Gender: Separate comparisons were conducted for each condition/gender combination. In the control condi-

tion, females exhibited shorter latencies to alcohol images (vs. objects), $F(1, 16) = 10.49$, $p = .005$. No other significant effects were noted ($ps > .09$). Time $\times$ Stimulus Type $\times$ Target Subgroup $\times$ Condition: Differences were nonsignificant following alpha adjustment.

P300 latency. Time, $F(1, 67) = 22.09$, $p < .001$ (shorter latency post-manipulation), and condition, $F(1, 67) = 9.03$, $p = .004$ (shorter latency to stressor), were significant factors, along with their interaction, $F(1, 67) = 4.97$, $p = .03$. In the stress condition, latencies were shorter following the stressor, $t(1, 37) = 4.50$, $p < .001$. In the control condition, differences were nonsignificant ($p = .06$). Stimulus type was also significant, $F(1, 67) = 10.40$, $p = .002$, and stimulus type interacted with time, $F(1, 67) = 4.76$, $p = .03$. Pre-manipulation, no differences were noted based on stimulus type ($p = .25$). Post-manipulation, latency was shorter to alcohol images versus objects, $t(1, 74) = 3.59$, $p = .001$.

Condition, gender, and their interactions were nonsignificant; no other effects were noted ($ps \geq .11$).

N3/P3 latency difference. Stimulus type was significant, $F(1, 67) = 5.85$, $p = .02$ (smaller latency difference to alcohol images), as was condition, $F(1, 71) = 5.71$, $p = .02$ (smaller latency differences in stress condition). No other effects were noted ($ps > .10$).

Discussion

Stress is an important factor in the decision to consume alcohol (e.g., Pohorecky, 1991). However, the mechanisms that underlie the relationship between stress and appetitive

motivations toward alcohol are poorly understood. This study examined ERP correlates of attentional capture by alcohol images before and after an acute stressor versus a control condition. The authors predicted that stress would enhance ERPs to alcohol images (e.g., a Time $\times$ Condition interaction). Using the Wiers et al. (2007) model as a framework, the ability of alcohol images to capture attention is the result of a combination of automatic (approach-oriented) and controlled (self-regulatory) processes, such that early appetitive responses are heightened, whereas later self-regulatory processes are weakened. Therefore, the influence of automatic processes should be manifested earlier in the processing stream and may appear as ERP enhancement independent of the target subgroup (e.g., main effect of stimulus type showing enhanced amplitudes for alcohol images regardless of their target status). Alternatively, controlled processing should be manifested in later ERP components, in particular by a Stimulus Type $\times$ Target Status interaction where amplitudes are enhanced to alcohol images for the alcohol target group (e.g., reflecting the symbiotic effects of controlled and automatic processing), with no differences between stimulus types in the object target subgroup (e.g., alcohol images are capturing attention to the same extent as objects, even though they are to-be-ignored images). Successful controlled processing was expected to be reflected by target subgroup effects, where amplitudes for targets would always be larger, regardless of image type.

For N200 amplitude, target subgroup was a main determinant of amplitudes to alcohol images. Further, the four-way interaction demonstrated that stress enhanced N200 amplitudes to both image types, regardless of their target status. In contrast, a larger N200 amplitude to object nontargets in the alcohol target subgroup was observed in the control condition. A lack of significant findings within the stress condition for the alcohol target subgroup suggests that the stressor may have interfered with the traditional mismatch effect in this group.

For N200 latency, a Time $\times$ Experimental Condition effect supported the prediction of stress-related decreases in ERP latency beyond practice effects. Gender influenced N200 latency, in that females exhibited shorter latencies to alcohol images within the control condition, regardless of their target status.

P300 amplitude was not enhanced by stress, but stimulus type interacted with target status. P300 amplitudes were enhanced for alcohol targets, which may have been the result of symbiotic effects of both automatic and controlled processing during the presentation of alcohol-related images. However, there were no differences between object targets and alcohol nontargets in the object target condition, suggesting that alcohol images were capturing attention even though they were task irrelevant (i.e., a failure of controlled processing). The four-way interaction indicated that participants assigned to the control condition exhibited the

expected P300 oddball effect (i.e., larger P300 to alcohol targets in the alcohol target subgroup), whereas those within the stress condition did not. A lack of significant findings within the stress condition suggests that stress may have subtly interfered with participants' cognitive efficiency (e.g., the ability to isolate and ignore irrelevancy; Nixon et al., 1998).

For P300 latency, there was an interaction of Time $\times$ Experimental Condition. P300 latency was decreased by stress beyond practice effects. Further, a Stimulus Type $\times$ Experimental Condition interaction occurred. Manipulation-related changes were twice as large in response to alcohol stimuli compared with object stimuli, regardless of target condition. This supports the role of automatic processes in attentional capture by alcohol stimuli. The stress condition elicited smaller N2/P3 latency differences overall, and latency differences were smaller to alcohol versus objects across experimental conditions.

For N2/P3 amplitude differences, target subgroup was a determinant of response to alcohol images (i.e., larger P300 to alcohol targets in the alcohol target subgroup), suggesting controlled processing of alcohol-related images. The three-way interaction of Time $\times$ Stimulus Type $\times$ Target Subgroup revealed differential effects for alcohol and object target groups. Within the alcohol target subgroup, amplitude differences were enhanced by alcohol images, but this effect was not selectively impacted by the stressor. Within the object target subgroup, response to alcohol images did not differ as a function of experimental condition. Response to object images was enhanced by both manipulations. Overall, N2/P3 latency differences were smaller to alcohol images (vs. objects) and were smaller in the stress condition (vs. control), but no interactions were noted.

To summarize, findings of decreased latency of ERPs in response to stress are consistent with reports regarding noradrenergic activation of arousal/attention (Coull et al., 1999). Differential responsiveness to alcohol images within the target subgroups suggests that attention was moderated by both automatic and controlled processing of alcohol-related images, albeit appearing earlier in the ERP than might be expected (i.e., N200). Interactions of Stimulus Type $\times$ Experimental Condition, in which stress enhanced ERPs to alcohol images regardless of target status, suggest a stress-related increase in the salience of alcohol images. These findings are consistent with the view that stress increases the salience of emotional stimuli, which activates appetitive/motivational systems to enhance early processing (Wiers et al., 2007) and modulate prefrontal functioning (Liston et al., 2009). Importantly, P300 amplitudes were not sensitive to stress; P300 responses to alcohol remained stable despite short-term changes in emotional state. This is consistent with the notion that P300 amplitudes in response to alcohol images may serve as an endophenotypic marker of risk for alcohol use disorders (e.g., Bartholow et al., 2010).

Conclusion

Stress differentially affected ERPs to alcohol images, and effects were most pronounced for N200 amplitudes and latencies and P300 latencies. Target subgroup effects on P300 amplitudes to alcohol images supported the notion of controlled processing of alcohol stimuli. These results have implications for the understanding of cognitive processes involved in Stress $\times$ Alcohol interactions and could be particularly relevant for individuals who view alcohol consumption as a means of alleviating anxiety. Future studies are needed to examine these effects across social drinking categories and in the treatment-seeking population.

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